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ORIGINAL ARTICLE

Methodologies to Represent and Promote the Geoheritage Using Unmanned Aerial Vehicles, Multimedia Technologies, and Augmented Reality

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Abstract

Promoting geoheritage using the Internet materializes mainly through the use of maps, posters, informational murals, or websites. This information is usually detailed and visually appealing. However, in most cases, there is little interactivity and a limited or complete lack of contextualization within the geographical space. The main objective of this work was to integrate information collected with unmanned aerial vehicles, georeferenced information processed in geographical information systems, photogrammetry techniques, and multimedia technologies to promote a better computer visualization of geoheritage. A working website was built based on panoramic photography, three-dimensional representation of the terrain, and multimedia information, in order to provide a pleasant way of promoting and interacting with field geology by using the Internet. The navigation through the information is based on 360° spherical panoramic images that are fully oriented and georeferenced. Their movement can be perfectly synchronized with the viewing of the landscape by using motion sensors found on portable devices (tablets or smartphones) such as GPS, accelerometers, gyroscopes, or compasses. These images can include the access to multimedia elements such as websites, videos, images, sounds, interpretation models, text, or interactive 3D terrain models, working as an excellent support base for the provision of an augmented reality experience. If used in the field, this technical implementation can act as an interactive guide for the interpretation of the landscape. This type of content can be accessed online from locations with a network signal or can be obtained in advance for offline use.

Keywords Unmanned aerial vehicle (UAV) · Geoheritage · 3D · Panoramic 360° photography · Augmented reality

Introduction

The use of new forms for representation of the social and spatial dynamics using information technologies is being increasingly studied in the searching for associating efficient methods of representation of information to different viewing perspectives, exemplified in numerous examples cited by Cayla (2014). Therefore, it required the use of different mechanisms to obtain, store and deliver data, capable of reproducing the reality to be represented.

During the past decades, the development of new digital technologies has strongly influenced the scientific practices within the scope of geoheritage and research in geotourism. Digital tools, such as geographic information systems (GIS), have played an important role in the development of new processing methods and spatial information visualization, as well as in the assessment and mapping, allowing the development of proposals for new geosites with sound gains for geotourism and education (Cayla et al. 2014). Other good examples of geological/geoheritage

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mapping using GIS tools can be found in Bollati et al. (2016a), Carton et al. (2005), or Regolini-Bissig (2010).

Among some works that relate innovative ways of visualizing and acquiring knowledge, one can notice Martin et al. (2014) or Martin (2014), who conducted a survey of a group of individuals (with different backgrounds) on the understanding of geomorphological aspects, represented in various media supports. The author concluded that the three-dimensional (3D) visualization is a tool that allows a more efficient representation of information, being the only medium in which all the information that was intended to convey was noted by all individuals surveyed. It has also been identified as the most appealing information transmission method. This example shows that for a public not specialized in Earth Sciences, 3D representation may be the way which allow giving a clearer view of reality and, also, relating the information to the real objects (geomorphological, geological, etc.).

Under this perspective, some methodologies associated with the application of photogrammetry have brought results that allow representing different aspects of reality in various scientific areas of the natural sciences. Good examples are Martin et al. (2014) and Aldighieri et al. (2016).

In this sense, there have been several technological applications capable of providing and popularizing these methodologies, in an accessible way to promote geographic knowledge, such as the application "Maps" of Apple Computer and "Google Earth" from Google Inc. (including, among other features, "Google Street View"). Both applications already reproduce information obtained through photogrammetry techniques, materialized in 3D information, free of charge and with a low complexity of use. Both applications use image databases, generated from satellites or from aerial photography, and altimetry data, usually from NASA's Shuttle Radar Topography Mission (Farr et al. 2007) to give a 3D terrain interaction. However, the availability of photographic information in those two applications does not always have the desired resolution on the entire surface of the Earth, as this depends on the availability, scale, and frequency of the images obtained. Thus, more detailed information tends to be concentrated along the major urban centers. Also, the available NASA's SRTM 3D data has a Ground Sampling Distance (GSD) of 90 or 30 m, which is very coarse to represent some geological structures whose size is hectometric or less.

This aspect is limiting in the promotion of geoheritage since, except for a few rare places of geological interest with world relevance, the overwhelming majority of geosites, in particular those that are further away from urban centers, are shown with low or very low resolution in both imagery and 3D terrain model. Focusing on the importance of investigating spatio-temporal changes of sites of geomorphological heritage (Bollati et al. 2016a, b), some work has been done using terrestrial LIDAR systems to obtain accurate 3D data of geological features (e.g., Ravanel et al. 2014).

Against this background, the use of new methods for obtaining photogrammetric data is desirable, based on easily portable and affordable equipment that can enable rapid and recurring use in areas that are not easily accessible. The recent development of Unmanned Aerial Vehicles (UAVs), simple to use and equipped with high-resolution cameras, makes these devices particularly suited for this task (Gonçalves and Henriques 2015).

The use of UAVs is applied in various fields such as agriculture (Medeiros et al. 2008; Freitas and Cottet 2010; GAO 2008), environmental sciences (Gonçalves and Henriques 2015), cultural heritage (Joppa 2015), archeology (Konstantinos et al. 2017), military purposes (Gonçalves and Henriques 2015), and advertising. These tools are able to take vertical or oblique images at various scales depending on the flying height according to the user's interest. They also have the possibility to collect images according to a preliminary flight plan for photogrammetric purposes, or to comply with other user-defined trajectories, such as orbits around objects of interest, GPS waypoint navigation, user chase modes, object and tracking. One of the particularly interesting flight plans for use in geoheritage is the possibility of obtaining panoramic images. These images are based on the application of photogrammetric principles to a series of sequential overlapping images, obtained from the same point (nodal point) at different angles, which are further assembled in a single image that covers the entire observable surround.

These images allow the visualization of all the context that is situated around the nodal point, centered on the position of the unmanned aerial vehicle itself, and can be converted into an interactive panoramic image, navigable to 360°. This technique allows a wide visual perspective of the landscape, and an air vantage point, impossible to obtain by a satellite, from a conventional plane or by an observer on the ground. The acquisition of field data by an observer near the ground tends to be limited. This observer's perspective is commonly implicit in the images obtained, in interpretive schemes of the landscape, etc. This conditioning leads to the fact that most of the represented images of a certain site of geological interest always tend to have the same point of observation and a limited field of view. Using unmanned aerial vehicles and panoramic images gives us different points of view from those that are possible from the ground, allowing the observation of the landscape in a different and sometimes more interesting way and with unlimited field of view.

According to Soares and Zuffo (2004), in the last 50 years, several simulation and visualization technologies have been developed, allowing the creation of immersive and semi-immersive environments. The term "immersive" is related to the degree to which the user simulates a system or landscape relative to actual experience in a three-dimensional world. Non-immersive is related with the direct observation of a computer monitor. Semi-immersive systems are those that partially simulate the real-world experience, like the use of sensors to simulate movement or concave screens that simulates the landscape view or the interior of an airplane in a flight simulator. Immersive systems are those that use an extensive set of technology to simulate, as realistically as possible, the real-world experience. In this case, it is common the use of virtual reality (VR) glasses or 360° projection walls (floor and roof can also be included), speakers at different angles with real-world sound/music, tracking sensors to react to user movement, etc. The set of methodologies and technologies for creating fully immersive interactive environments are also known as VR.

One of the key aspects that has guided this work was the possibility of applying the various products generated from images obtained using unmanned aerial vehicles, underpinned by information technology and tools of geosciences and geoheritage representation (Santos 2017).

Many authors (Carlis and Konstan 1999; Gershon and Eick 1997; Lansigu et al. 2014; Martin et al. 2014; Martin 2014; Hoblea et al. 2014; Aldighieri et al. 2016; Bollati et al. 2016a, b) have improved the quality of visualization, arising from use of analog information representation with more than one dimension, combined with techniques for incorporating additional contents such as text, maps, images, photographs, and sounds. An impressive example using 3D animation can be accessed from http://archeologie.culture.fr/lascaux/fr/visiter-grotte-lascaux. Additionally, there are several examples of technological information systems and visualization applications, employing various features, such as representations through three-dimensional models, augmented reality, and web interface, among others, sometimes organizes as virtual tours. Several examples can be found in Bertok et al. (2014), Martínez-Graña et al. (2017), and Triantafyllou et al. (2017).

Virtual reality allows the expansion of viewing possibilities, breaking the computer monitor screen barrier (Kirner and Martins 2000). With the use of virtual reality, an infinite-dimensional space can be achieved, in which 3D graphics can be arranged and where anyone can navigate and interact. However, to make this feature accessible to users, it must be integrated in a proper viewing platform. With current hardware limitations, this technology is more likely to be used in museums and is not yet suitable for field use.

In this work, we propose a way of interacting with multimedia information about the landscape, in a semi-immersive way, based on 360° panoramic images, that can be used indoor or in the field. Interacting with this information is, from a technological point of view, limited by the existing online software solutions and by the hardware power, in order to manipulate the objects represented in the interface with sufficient fluidity display. The HTML5 language makes available, online, three-dimensional models generated from photogrammetric data for unmanned aerial vehicles as it will be shown further in this work.

The HTML5 is being developed as the next major revision of Hypertext Markup Language (HTML), marking the WWW (World Wide Web) language core (Boulos et al. 2010). The main goal is to reduce the need to use additional plug-ins to perform the most common applications of navigation, such as Adobe Flash, Microsoft Silverlight, and JavaFX Oracle -Sun. YouTube, for example, is planning a HTML5 version of its service that dispenses "Adobe Flash," but instead uses HTML5 to play videos in web browsers. Likewise, Apple Computer dropped support of "Adobe Flash" on their mobile platforms, based on the iOS operating system, in favor of HTML5. This conversion represents a form of reducing access time and optimizing memory consumption, when it is desired to play a large volume of information grouped in the same web window, as in the case of three-dimensional terrain models. Three-dimensional models can be perfectly used individually to represent a place, a structure or, an assemblage of both. They can also be integrated into online platforms or be printed on three-dimensional printers. To obtain quality images, necessary for the creation of these models, unmanned aerial vehicles or handheld cameras can be used. Usually, large-sized areas require unmanned aerial vehicles imagery while small structures, with metric or sub-metric size, can be captured using a handheld camera.

For processing these images, there are several photogrammetry applications available in the market today. These can be complemented with GIS applications, Open Source or licensed, able to compile the image files with the geographic database, related with the research in question. Currently, the use of Open Source GIS software optimizes time and costs and has the technological strength necessary to accomplish the job.

Methodology

Fieldwork and Pre-flight Planning

The first phase of work requires the planning of information collection sites, as well as the field survey of the terrain constraints that can guide the design of the corresponding flight plans. In this case, every potential obstacle, such as wind towers, powerlines, and trees, are located in order to design a safe flight plan. Several early flights, with video and photography collection, were made manually in order to identify potential locations where elements of geological and geomorphological interest could be present.

A simple georeferenced database, containing the location of the sites of geological interest to be photographed, using panoramic photography or 3D mapping, as well as the orientation and the number of photographs to be acquired at each point, was created from this information. In addition to the sites of scientific interest—geosites were also selected geodiversity sites with educational and tourist interest (Brilha 2016).

Acquisition of Information

The images needed for the several contents (panoramic images, 3D models, etc.) were collected in the field using the unmanned aerial vehicles and a handheld camera. The main locations chosen to be used for prototype building were Serra de Fafe, a location dominated by granite morphology, studied by Loureiro (2015), and Terras de Cavaleiros Global Geopark, whose information can be found in "http://geoparkterrasdecavaleiros.net/pt-pt" (Fig. 1).

The type of flight planning was chosen based on the type of information to be collected.

For panoramic images, panorama flight mode was used with the help of Litchi software (flylitchi.com). In this flight mode, the unmanned aerial vehicle is fixed in one GPS location (nodal point) and then makes rotations of about 36° horizontally in a total of ten columns and the camera is also tilted about 45° vertically in a total of three rows. This way, about 30 pictures are obtained, covering the surroundings of the nodal point. Only the zenithal view of the sky is not obtained because is occulted by the unmanned aerial vehicle.

For 3D modelling or 3D mapping, two kinds of flights were used: parallel lines, orbital.

The flight in parallel lines is the common flight style for 3D mapping purposes. These lines must cover all the survey area. The unmanned aerial vehicle will fly along these lines taking pictures at a certain interval. Images are taken ensuring an overlap of at least 60% both in X and Y between each pair of consecutive images. The software Map Pilot from Drones Made Easy was used for this purpose (http://www.dronesmadeeasy.com).

The orbital flight is appropriate to make the 3D reconstruction of isolated objects in the landscape. In this case, the drone will make an orbital flight with the object in the middle, ensuring that the camera is always pointed to the object. Pictures are taken from several points of view, ensuring that enough overlap will occur to allow the geometrical correlation of the same features in the object during the photogrammetric processing. Most of these flights were made manually but they can also be accomplished using Litchi software for instance.

Some images of local physical data (geological, geomorphological) were also collected from the ground, using a handheld camera, to be integrated within panoramic images as elements of augmented reality.

To obtain aerial imagery, two UAVs with attached cameras were used (GoPro Hero 4 Silver—for Walkera X350 Pro; ZenMuse X3—for DJi Inspire 1). The choice of these devices was conditioned by the tests carried out in the field, having been privileged the speed shown in image acquisition and optimization of the data post-processing, considering that the imaging is performed only within the range of interest and does not require many procedures related with the crop of the spatial area (Fig. 2).

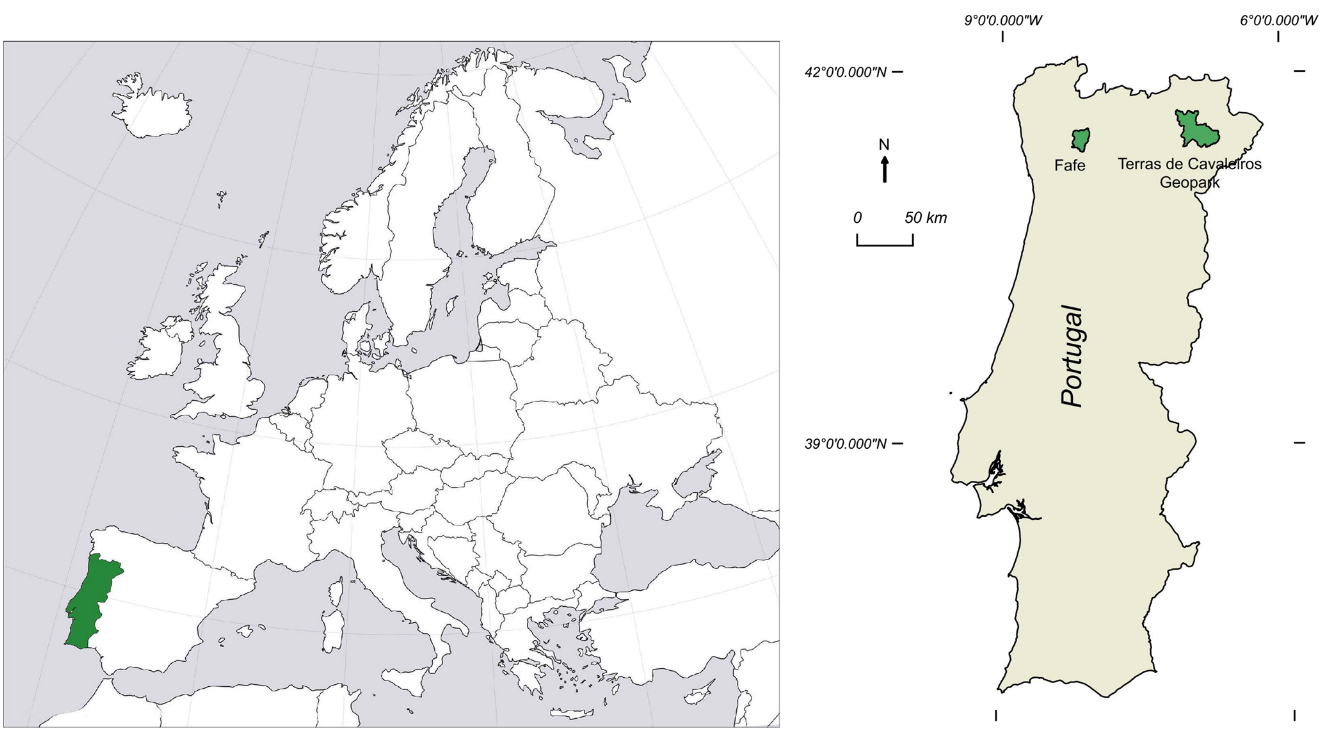

Fig. 1 Location of the areas of Fafe and Terras de Cavaleiros Geopark, where the acquisition of information took place (*Coordinates in WGS84—EPSG 4326*)

Fig. 2 **a**–**c** Fieldwork for image acquisition, Granite landscape, Fafe, Portugal—Walkera X350 Pro unmanned aerial vehicle; **d** DJi Inspire 1 unmanned aerial vehicle, taken near "Pedra do Boi"—Fafe, Portugal.

Photogrammetric Processing

The images collected using unmanned aerial vehicles were processed in order to obtain panoramic images and 3D interactive objects using the photogrammetric applications: Agisoft Photoscan (www.agisoft.com), Autopano Giga (www.kolor.com). Quantum GIS Open Source software (www.qgis.org) was used to compile the database of georeferenced information, to correctly position all obtained graphical objects, 3D elements, and the nodal point of the panoramic images as well as their azimuthal orientation. At this stage, the images obtained in the field work were selected. These images had already georeferenced information, that was possible through the on-board GPS sensor and the unmanned aerial vehicle firmware, configured for compatibility with the airborne camera, which links the geographical location to every image taken and embeds it in the file EXIF data. To obtain panoramic images, single images have been selected and then processed with the software Autopano Giga. This application is relatively automatic, but important tuning steps must be selected and mediated by the user. The images were finally edited in the image editing software Adobe Photoshop (www.adobe.com) for graphic tuning and complement missing elements (Fig. 2). One of these missing elements was, usually, part of the sky around the zenith point as described earlier. In this case, the sky is given the nature of the unmanned aerial vehicle equipment used, based on two quadcopters—the Walkera X350 Pro and DJi Inspire 1; the acquisition of images for panoramic photo purposes occurs through the rotation of the unmanned aerial vehicle or the rotation of the gimbal (camera stand with three-axis servo-motor stabilization). Usually, the camera is positioned at the bottom of the unmanned aerial vehicle equipment. Thus, images from the nadir and all the surrounding landscape until about 40° above the horizon are obtained without any masking. Above this angle, which usually includes the sky until the zenith, the images suffer from occultation by the fuselage of the unmanned aerial vehicle itself and by its propulsion system. In practice, this occultation means that the zenithal sky does not appear because the respective photos are not possible to obtain. The sky is, then, artificially implanted or populated based on the photographic conditions of exposure and atmospheric elements (color of the sky, clouds, light, etc.) observed in the photographed portions.

For the three-dimensional reconstruction of isolated objects, the software Agisoft Photoscan was used. This reconstruction involves six steps shown in Fig. 3a–f:

a) The first phase of creating three-dimensional models from aerial photography is the detection and correlation of common points (matching) and the establishment of their relative geometric position. In this phase, the relative position of the cameras is obtained, as well as a sparse point cloud.

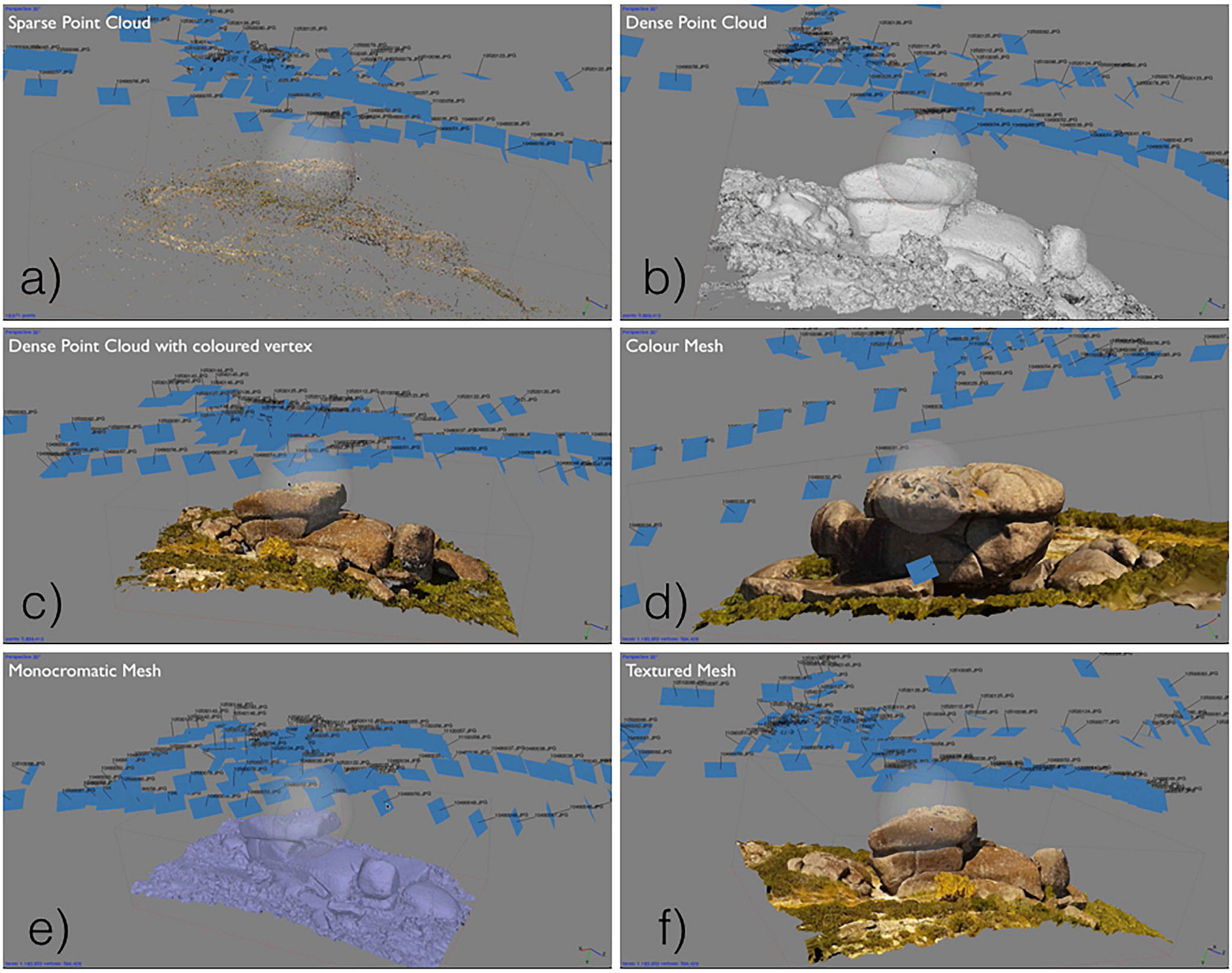

Fig. 3 **a**–**f** Steps for three-dimensional modelling (Granite landscape, Fafe, Portugal)

b) The second step for three-dimensional models is to obtain a dense point cloud, resulting from the mathematical densification of the sparse point cloud. The model detail increases significantly when compared with the previous stage.
c) This point cloud is exactly like the previous one; however, each vertex is colored based on the information obtained from the photos. Thus, there is an illusion of more detail provided by the model. It is possible to zoom the model, maintaining a good resolution.
d) The third phase of obtaining three-dimensional models is to create a continuous mesh. This process is based on the creation of polygons resulting from the triangulation of all points of the dense point cloud. Thus, a continuous surface is generated for the model, getting visually closer to the reality. The model detail increases due to a better filling of all the small details, resulting in better sharpness and overall quality.
e) The mesh can be viewed without color, allowing the check the quality of the model detail when compared to the real object photographed. Zoom can be used. Because there is a filtering process of the dense point cloud while building up the mesh, a significant portion of the model noise is eliminated. This view allows the manual removal of small defects such as detached elements or excess geometry or any remaining error that was not eliminated in the dense point cloud filtering process.
f) The final model to be made available has a photographic texture overlaid in the continuous mesh, based on a mosaic of all the photos. As this is the real photographic information obtained by the camera, the model assumes great realism, allowing the manipulation and visualization of the geological or geomorphological object with great detail. This information is then processed by the software *Keyshot Pro* (www.keyshot.com) which allows these models to be converted into interactive elements, based on

HTML5 language, providing the possibility of interaction via a web interface.

The three-dimensional model can be used individually or, if appropriate, can be associated to other complementary information, like text for instance, in virtual web-based interactive platforms. The integration is also done using HTML5 language. These 3D models can also be 3D printed to be used as mock-ups or replicas for museums for instance.

Integration into Virtual Tours

After the image processing stage, which includes the photogrammetric processing, GIS, image editing, and layout for insertion of data elements, a virtual tour is produced. The compilation and integration of all the interactive elements for this purpose are made using the application Kolor Panotour (www.kolor.com). All the assemblage of the panoramic images with the various multimedia elements is made using tools provided by this application.

Results and Discussion

The representation of the geoheritage requires a simple and accessible language, as part of the set of dissemination and exploitation tools. This context involves different sectors of the society as players: scientific community, general public and stakeholders. Thus, the language of representation must be universal, and to integrate these actors in the knowledge of the existence of assets, the value of initiatives and awareness actions of conservation of these environments. The produced prototypes aim to include, in the future, all these values. In the present state, they are still a "proof of concept," to show how panoramic images can be the base for a semi-immersive geographical aware database, that can be easily explored by the public in general, using only a web browser.

The obtained panoramic images have, in general, excellent quality. The use of unmanned aerial vehicles allows us to generate a set of panoramic images in places of difficult access and/or from a perspective that cannot be observed from the ground (Fig. 4).

Images usually stitch without major problems, unless the unmanned aerial vehicle shows a major drift from the nodal point during the panorama single image acquisition. In this case, images must be forced to stich correctly with the use of manually implanted matching points. If these images are not correctly warped and stitched, the panorama acquisition must be repeated. These drifts from the unmanned aerial vehicle tend to occur more often in windy days. For this reason, if there is a persistence of wind gusts above 20 m/s or more, this kind of work must be avoided. Wind also implies the movement of vegetation or water. If moving features exist in the captured sites, they must be masked out in the photogrammetric software to increase the success of the common point matching process. Mostly, all the obtained panoramas were successfully produced without any major stitching problem.

A key aspect that interfered in the selected site representation quality is the period of the day during which the image is captured. In the morning, the images show a higher contrast silhouette effect in the background hills, more dramatic shadows, more saturated and contrasting colors, and a softer sky. At noon, there is often less contrast, more balanced and yellowish colors, less pronounced shadows, and a clear sky.

It was possible to create panoramic images of places of interest, aggregated to the description of the geoheritage through the use of additional information such as maps, legends, educational texts, external websites, interactive 3D interfaces, geology modelling, geomorphology, and associated contexts of the selected locations. Each attached element has been integrated into the panoramic image by programming, using HTML5 and JavaScript language. The use of such languages allows the edition of access buttons as well as text formatting, and the insertion of images, graphics, or sounds and other multimedia elements (Fig. 5). These elements are accessed through symbolic links, identified by small icons (animated or static) in the panoramic images (acting as hotspots), spatially contextualized, bringing them to the foreground with a click of the mouse or with a finger touch in the case of mobile platforms with touchscreen technology. This information also includes text, video sequences, and morphological elements converted in interactive 3D models (also with images made by unmanned aerial vehicle or manually). In the case of 3D interactive objects, the software Keyshot Pro (www.keyshot.com) was used to convert them into interactive elements, based on HTML5 language, providing the possibility of interaction via a web interface. In some cases, the Sketchfab online service (sketchfab.com) was also used for this purpose (see "Lage Branca – Fafe", "Lagoa – Fafe" or "Penedo do Boi" panoramas, included in the prototype referred to below, accessible from the link "http://www.dct.uminho.pt/macedo/macedo.html"). This approach, based on panoramic images, differs from other authors that used mainly Google Earth as the base for augmented reality elements, such as Martínez-Graña et al. (2017) or Triantafyllou et al. (2017).

Considering that all multimedia elements are editable information, different levels of detail can be provided in order to be suitable for different audiences. The main objective of the information relates to the interpretation, representation, and promotion of geodiversity sites (sensu Brilha 2016), with diverse interests such as scientific, educational, and scenic. Links for "Basic," "Intermediate," and "Advanced" levels of information can be provided.

These multimedia elements can provide a great experience of augmented reality on mobile computing platforms (tablets, smartphones) that have positioning sensors (compass,

Fig. 4 Panoramic image obtained by unmanned aerial vehicle (Terras de Cavaleiros Global Geopark)

gyroscope, GPS, and accelerometers). In these devices, the panoramic images can move automatically depending on the pointing azimuth and the device tilt angle. In this work, the information was processed in fully georeferenced mode, so there is a great correlation between what is being shown on the screen and the landscape itself to which the device is pointed. All layers with augmented reality can be activated or deactivated by the user (Fig. 6).

The access to the panoramic images, after corrections and processed in the form of a panoramic semi-immersive 360° image, follows a user-defined script, where hotspots with links are placed over the image to allow access to various items of information, as said earlier and, consequently, allowing the interpretation of the landscape. Each hotspot allows the access to multimedia elements contextualized to the geosite and can also set the navigation to other panoramic images of nearby places. They can also allow the access to animated evolution models that help to reconstruct the geological history of that point of interest. At the side of these panoramic images, a map can be generated from online mapping services, like Google or Bing maps, to help the user to know where was the image taken and to which direction the image is pointing. The map is interactive and geographically contextualized and a small angle cone visualization symbol is synchronized with any cursor movement. This is possible given that all data has been enriched with georeferenced information at the time of acquisition (Fig. 7).

The access to the several base panoramic images can be made through links via clickable points manually marked on a map or from menus. These panoramic images are then, as said, used to navigate through the surrounding landscape and allow the access to deeper levels of information such as web sites, other panoramic images or detailed 3D models of landscape features. These models allow us to interact with the geological features in a manner that it is impossible to do in regular or standard field work field. It is comparable of being able to fly over and around an object, in a complete interactive manner, allowing many different points of view that are impossible to have from the ground, favoring the discovery of features that no one noticed before. Considering that the 3D reconstruction is based on photography, the final object texture benefits from this fact because it is a high-quality mosaic of all the obtained images. This gives 3D objects a more detailed and realistic aspect when compared, for instance, with 3D objects obtained by using LIDAR. In this technology, only a small-resolution camera is used to color each point obtained by LIDAR with the approximate color of the same point in the landscape. The final models are very accurate geometrically but the color texture is far from the quality obtained using photogrammetric techniques.

The early prototypes developed in this work can be accessed through the link http://www.dct.uminho.pt/macedo/macedo.html

We think that this technological approach, by combining all the multimedia elements cited, mainly panoramic images and very accurate 3D terrain models, can be a resource in the characterization and interpretation of geodiversity elements since it allows different points of view than conventional ones, and can also help as an interpretive resource for these elements. If some of these elements can potentially constitute geoheritage, the same applies. For this reason, it can be an added help for, indirectly, be used in geodiversity interpretation or even geoheritage inventory and ranking.

Considering an integrated way to navigate to the contents, we have made some attempts to give the best spatial context possible to do this. The panoramic imagens can be accessed from a simple link, as the one provided, or from a common 2D map of an area, where an overview of the available locations can be shown.

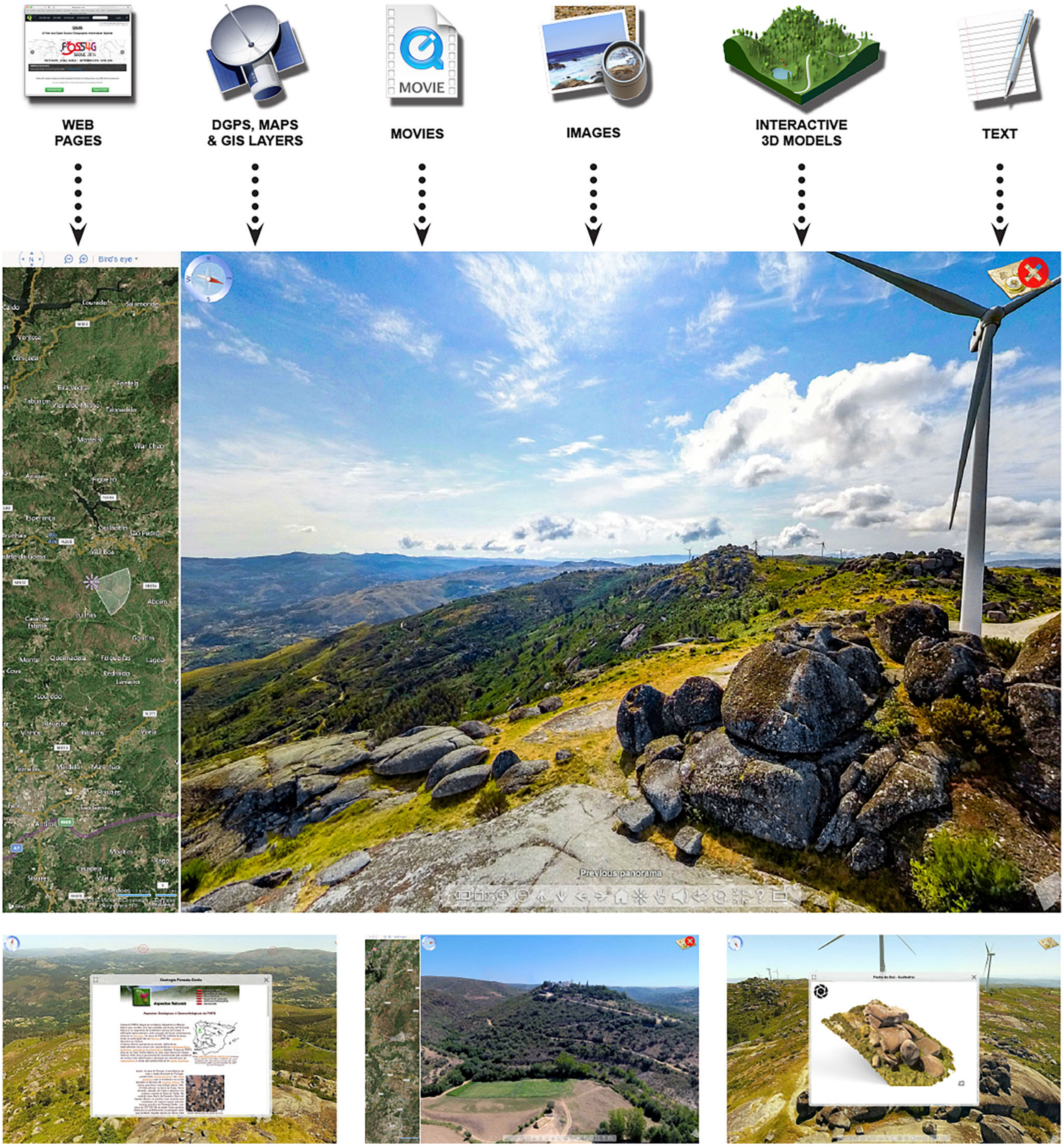

Fig. 5 Example of some information items included in the online overview and examples of screen shots to the user experience

However, we have been testing HTML interfaces based on real 3D navigation maps using WebCL frameworks, a JavaScript programming language framework for rendering 3D graphics without the use of plug-ins, compatible with most modern browsers. This platform was developed from JavaScript code to amend features and graphical aspects (Fig. 8).

This form of 3D representation may contain, in addition to geology and geomorphology of the selected location, the geoheritage inventory information as well as different levels of detail.

The points of each geological feature (or any other feature), as well as the geological map itself, can be clicked, making accessible the attribute table. This table can be fully modified to include information accessible to all audiences, ensuring easy access to several levels of scientific information, using efficient technology and maintaining a low production cost.

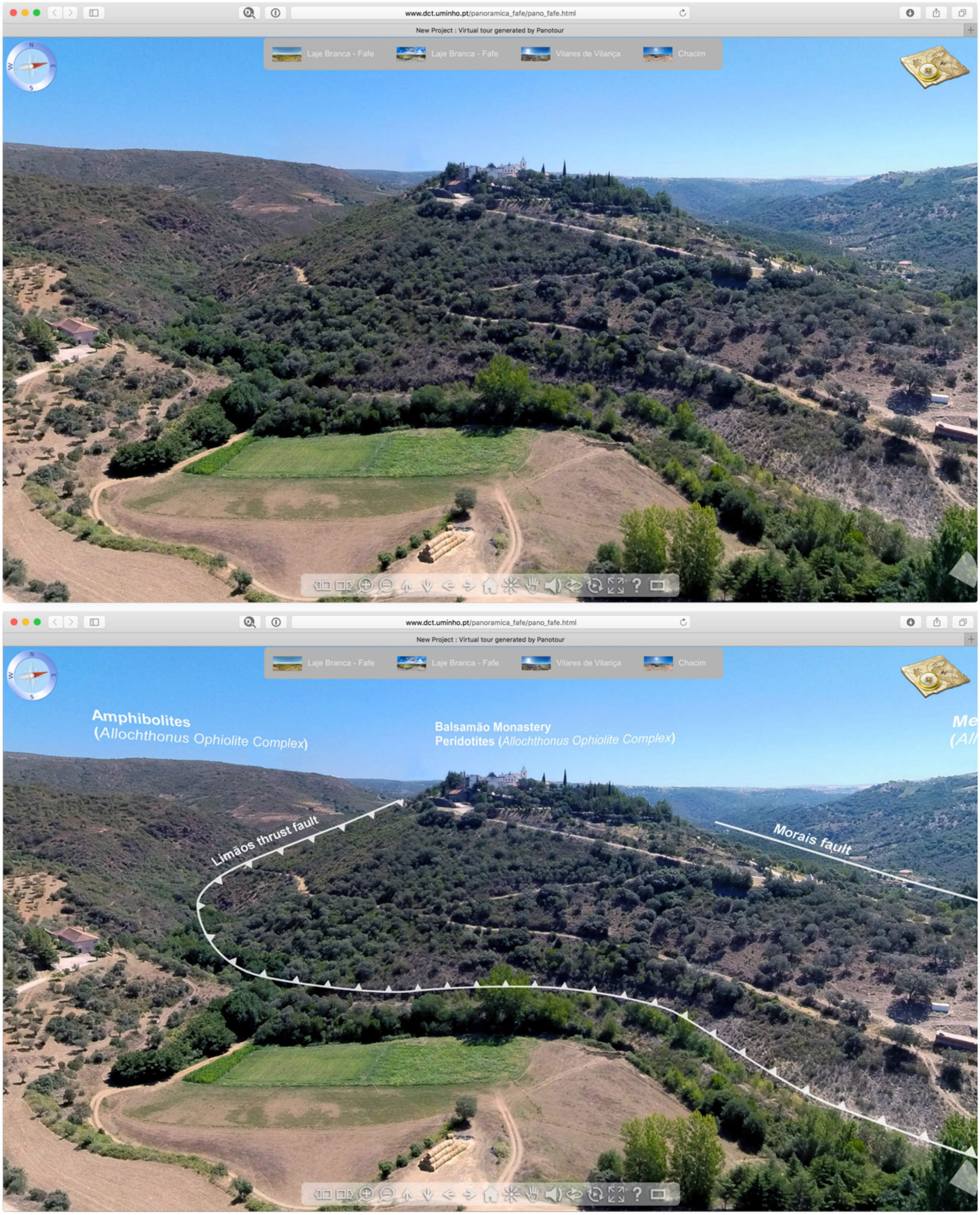

Fig. 6 Example of an interactive panorama, in the ofiolite sequence of Terras de Cavaleiros Global Geopark, without interpretation elements (top) and with geological interpretation with elements of augmented reality (below)

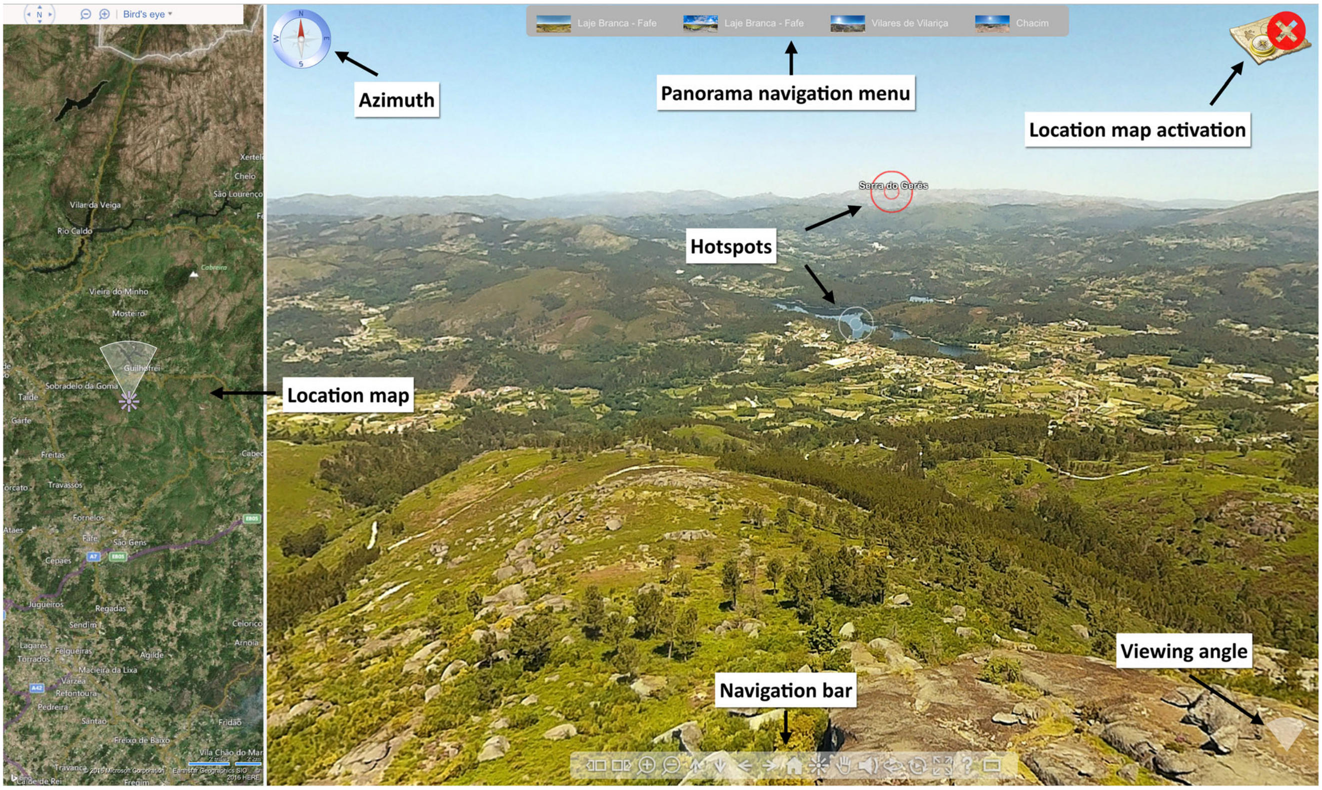

Fig. 7 Some interactive elements included in the online overview

These tables can also provide html links, for instance, for a contextualized panoramic image. An example of an early prototype is provided through the link http://www.dct.uminho.pt/macedo_geology/home.html

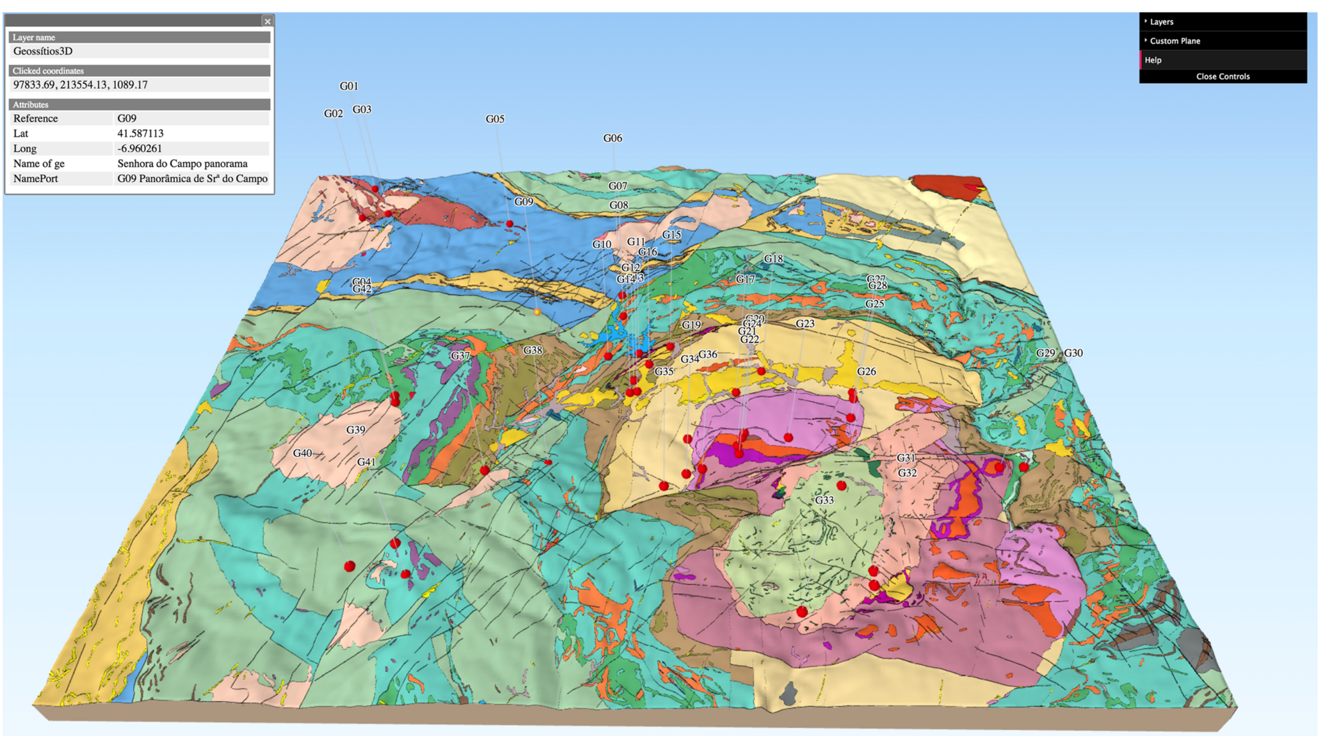

Fig. 8 Example of interactive 3D navigation interface, based on *WebCL* frameworks using a geological map coupled with the Digital Terrain Model of Terras de Cavaleiros Global Geopark

For devices non-compatible with *WebCL*, a most common 2D interface can be provided, also based on GIS information, for navigating the content.

This approach is different from the several examples of the work from other authors mentioned before, mostly based on Google Earth, because we can control from bottom to top what is the information that is shown or even the area and resolution of the base 3D model. This approach is also simpler to use because it does not need any third-party software (such as Google Earth). Only an Internet browser and Internet access is needed.These kinds of approaches are also very important to promote Earth Sciences knowledge among scholars. As pointed out by Bollati et al. (2016b), young students really appreciate these new technologies that, hence, may be used to motivate their interest towards Earth Sciences learning, especially because this method simply requires a mobile with Internet that is now usual among students.

Conclusions

The use of UAVs allowed us to obtain panoramic images and 3D models of great quality. This type of material has a high potential in the promotion of geoheritage and new ways of representing all the associated information. Through the integration of the products generated (3D models, panoramic photography, image data with views of privileged observation), it was possible to build virtual tours that can provide an added value in the dissemination of knowledge in geosciences and are a pleasant experience for exploring the landscape using information technologies. The access to this content is very simple and can be done by using any mobile Internet access device (tablet, smartphone, etc.), mostly provided with positional sensors, or using a portable or desktop computer. The user only has to know how to use a common Internet browsing application and access to an Internet site. Since access to these contents can be established using mobile devices (tablets, mobile phones with provided gyroscopes, compass, and accelerometers), these products can be used in the field and function as virtual guides and support the interpretation of the landscape with auto-consumption of information. They also represent an excellent mean of digital inclusion to target audiences with mobility restrictions, spatial and/or financial constraints for in-person visits. This approach is also a very important resource to promote Earth Sciences knowledge among scholars. The possibility of including augmented reality elements on the interactive images greatly enhances the multimedia experience and the educational and scientific potential of the provided information. Finally, these materials offer, from micro up to the macro scale, multiple options to represent the geological aspects, geomorphological, landscaped, etc., contributing significantly to the promotion of geoheritage.

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References

Aldighieri B, Testa B, Bertini A (2016) 3D exploration of the San Lucano Valley: virtual geo-routes for everyone who would like to understand the landscape of the Dolomites. Geoheritage 8:77–90. https://doi.org/10.1007/s12371-015-0164-x

Bertok C, Lozar F, Magagna A, Giordano E, d'Atri A, Dela Pierre F, Natalicchio M, Martire L, Clari P, Violanti D, Ghirald L (2014) Virtual tours through Earth's history and palaeoclimate: examples from the Piemonte (Northwestern Italy) Geoheritage (PROGEO-Piemonte Project). In: Rocha R, Pais J, Kullberg J, Finney S (eds) STRATI 2013. Springer Geology. Springer, Cham. https://doi.org/10.1007/978-3-319-04364-7_60

Bollati I, Fossati M, Zanoletti E, Zucali M, Magagna A, Pelfini M (2016a) A methodological proposal for the assessment of cliffs equipped for climbing as a component of geoheritage and tools for Earth Science education: the case of the Verbano- Cusio-Ossola (Western Italian Alps). In: Skourtsos E, Lister G (eds) General contributions, Journal of the Virtual Explorer, Electronic Edition, Volume 49, paper 1, 1–23

Bollati I, Reynard E, Lupia Palmieri E, Pelfini M (2016b) Runoff impact on active geomorphosites in unconsolidated substrate. A comparison between landforms in glacial and marine clay sediments: two case studies from the Swiss Alps and the Italian Apennines. Geoheritage 8(1):61–75. https://doi.org/10.1007/s12371-015-0161-0

Boulos MN, Warren J, Gong J, Yue P (2010) Web GIS in practice VIII: HTML5 and the canvas element for interactive online mapping. Int J Health Geogr 9:14

Brilha J (2016) Inventory and quantitative assessment of geosites and geodiversity sites: a review. Geoheritage 1–16. https://doi.org/10.1007/s12371-014-0139-3

Carlis JV, Konstan JA (1999) Interactive visualization of serial periodic data. Proceedings of the IEEE Symposium on Information Visualization, p. 29–38

Carton A, Coratza P, Marchetti M (2005) Guidelines for geomorphological sites mapping: examples from Italy. Géomorphologie: Relief, Processus, Environnement. n° 3 Géomorphosites : définition, évaluation et cartographie 11(3):209–218. https://doi.org/10.4000/geomorphologie.374

Cayla N (2014) An overview of new technologies applied to the management of geoheritage. Geoheritage 6:91–102. https://doi.org/10.1007/s12371-014-0113-0

Cayla N, Hobléa F, Reynard E (2014) New digital technologies applied to the management of geoheritage. Geoheritage 6(2):89–90

Farr TG, Rosen PA, Caro E, Crippen R, Duren R, Hensley S, Kobrick M, Paller M, Rodriguez E, Roth L, Seal D, Shaffer S, Shimada J, Umland J, Werner M, Oskin M, Burbank D, Alsdorf D (2007) The shuttle radar topography mission. Rev Geophys 45:RG2004. https://doi.org/10.1029/2005RG000183

Freitas E, Cottet F (2010) A invasão dos VANTs: Veículos aéreos não tripulados já são realidade no setor de sensoriamento remoto In: INFOGEO n° 60. MundoGeo. Curitiba-PR

GAO (2008) Unmanned aircraft systems - federal actions needed to ensure safety and expand their potential uses within the national airspace system. [S.l.]: GAO, (GAO-08-511)

Gershon ND, Eick SG (1997) Information visualization applications in the real world. IEEE Computer Graphics and Applications, July/August 1997, p. 66–70

Gonçalves JA, Henriques R (2015) UAV photogrammetry for topographic monitoring of coastal areas. ISPRS J Photogramm Remote Sens 104:101–111 https://doi.org/10.1016/j.isprsjprs.2015.02.009

Hoblea F, Delannoy JJ, Jaillet E, Ployon E, Sadier B (2014) Digital tools for managing and promoting karst geosites in Southeast France. Geoheritage 6:113–127. https://doi.org/10.1007/s12371-014-0112-1

Joppa LN (2015) Technology for nature conservation: an industry perspective. Ambio 44(Suppl. 4):522–526. https://doi.org/10.1007/s13280-015-0702-4

Konstantinos G, Konstantina S, Ioannis K, Nikolaos G (2017) UAV vs classical aerial photogrammetry for archaeological studies. J Archaeolog Sci Rep 14:758–773. https://doi.org/10.1016/j.jasrep.2016.09.004

Lansigu C, Bosse-Lansigu V, Le Hebel F (2014) Tools and methods used to represent geological processes and geosites: graphic and animated media as a means to popularize the scientific content and value of geoheritage. Geoheritage 6:159–168. https://doi.org/10.1007/s12371-014-0101-4

Loureiro CN (2015) Avaliação e Valorização do Património Geológico do Concelho de Fafe. Universidade do Minho, Portugal. Dissertação de Mestrado

Martin S (2013) Valoriser le géopatrimione par la médiation indirecte et la visualisation des objes géomorphologiques. Université de Lausanne. Tese de doutoramento

Martin S (2014) Interactive visual Media for geomorphological heritage interpretation. Theoretical approach and examples. Geoheritage 6: 149–157. https://doi.org/10.1007/s12371-014-0107-y

Martin S, Reynard E, Pellitero OR, Ghiraldi L (2014) Multiscale web mapping for geoheritage visualisation and promotion. Geoheritage Springer. https://doi.org/10.1007/s12371-014-0102-3

Martínez-Graña AM, Legoinha P, González-Delgado JA, Dabrio CJ, Pais J, Goy JL, Zazo C, Civis J, Armenteros I, Alonso-Gavilan G, Dias R, Cunha T (2017) Augmented reality in a hiking tour of the Miocene Geoheritage of the Central Algarve cliffs (Portugal). Geoheritage 9: 121–131. https://doi.org/10.1007/s12371-016-0182-3

Medeiros FA, Alonço AS, Balestra MRG, Dias VO, Landerhal Júnior ML (2008) Utilização de um veículo aéreo não-tripulado em atividades de imageamento georreferenciado. Ciência Rural, Santa Maria 38(8):2375–2378

Ravanel L, Bodin X, Deline P (2014) Using terrestrial laser scanning for the recognition and promotion of high-alpine geomorphosites. Geoheritage 6(2):129–140

Regolini-Bissig G (2010) Mapping geoheritage for interpretive purpose: definition and interdisciplinary approach. In: Regolini-Bissig G, Reynard E (eds) Mapping Geoheritage, Géovisions, Geography Institute, Lausanne, 35. pp. 1–13

Santos IO (2017) Novas metodologias para representação geoespacial e valorização dos elementos da geodiversidade: integração de geotecnologias, recursos online e realidade aumentada. Tese de doutoramento. Universidade Federal de Pernambuco, Brasil

Soares LP, Zuffo MK (2004) JINX: an X3D browser for VR immersive simulation based on clusters of commodity computers. ISBN: 1-58113-845-8. ACM New York, NY, USA ©2004

Triantafyllou A, Watlet A, Bastin C (2017) Geolokit: an interactive tool for visualising and exploring geoscientific data in Google Earth. Int J Appl Earth Obs Geoinf 62:39–46